Lumbar compression forces during while lifting and carrying tasks with two and four workers

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Lumbar compression forces while lifting and carrying with two and four workers

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ABSTRACT

Team lifting and carrying is advised when loads exceed 25 kg and mechanical lifting is not feasible. The aim of this study was to assess mean, maximum and variability of peak lumbar compression forces which occur daily at construction sites. Therefore, 12 ironworkers performed 50-kg two-worker and 100-kg four-worker lifting and carrying tasks in a laboratory experiment. The 50-kg two-worker lifts resulted in significantly higher mean (Δ 537 N) and maximum (Δ 586 N) peak lumbar compression forces compared with the 100-kg four-worker lifts. The lowest mean and maximum peak lumbar compression forces were found while carrying on level ground and increased significantly when stepping over obstacles and up platforms. Lifting 100 kg with four workers in a rectangular line up resulted in lower compression forces compared with lifting 50 kg with two workers standing next to each other. When loads are carried manually routes should be free of any obstacles to be overcome.

1. Introduction

In the construction industry, lifting loads is a frequently occurrence (e.g. Paquet et al., 2005; Hartmann and Fleischer, 2005). Manual material handling (MMH), in terms of lifting (e.g. da Costa and Vieira, 2010; Lötters et al., 2003; Kuiper et al., 2005; Hoogendoorn et al., 1999; Griffith et al., 2012) and carrying (Health Council of the Netherlands, 2012) is associated with an increased incidence of work-related back disorders. To prevent work-related back disorders as a result of lifting, the maximum load mass to be lifted by one worker has been set at 25 kg in the Netherlands, and the maximum load for manually lifting is set at 50 kg when lifted by two workers (Dutch Labour Inspectorate, 2012). Loads above 50 kg should always be lifted mechanically (Dutch Labour Inspectorate, 2012). However, mechanical transportation is not always feasible and when not available the loads should be lifted by more workers (team lifting), while not exceeding 25 kg per worker.

In concrete reinforcement tasks, previous field studies (Visser et al., 2014; Buchholz et al., 2003) have observed a variety of MMH tasks, including single-worker and team lifts and carrying. No differences were found for the duration of MMH (21% and 24% of the workday) when lifting maximally 50 kg or maximally 100 kg was allowed (Visser et al., 2014). Although most lifts were performed by one ironworker, 23%–37% of the lifts were performed by two or more ironworkers. However, in these field studies, the spinal loading during these MMH tasks were not quantified. In addition, physical workloads are also influenced by the worksite characteristics, such as obstacles (Haslam et al., 2005; Koningsveld et al., 2005) especially for carrying tasks.

Team lifting has been the subject of several studies (Dennis and Barrett, 2003a,b, 2002; Marras et al., 1999; Mital and Motorwala, 1995; Lee, 2004; Lee and Lee, 2001; Sharp et al., 1997). Of these studies, two compared the peak lumbar compression forces of single-worker- and two-worker lifts. The peak lumbar compression force was found to be lower for the two-worker lifts compared with the single-worker lifts (Dennis and Barrett, 2002; Marras et al., 1999). Similar results were found for carrying tasks (Marras et al., 1999). Studies on lifting with more than two workers did not report spinal loading, but did report that the maximal acceptable

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weight of lift (MAWL) was not different between two-worker lifts and four-worker lifts (Lee, 2004; Sharp et al., 1997). The effect of four-worker lifts on the spinal loading is, however, still unknown. With increasing the number of workers lifting a load, the coordination between worker may be influenced (Marras et al., 1999). This results in a variability of spinal loading because differences in coordination might result in unequal mass distribution with higher spinal loads for the worker at the heavier end (Dennis and Barrett, 2003b). Variability in spinal loading can also occur when a team has to step over an obstacle or up an elevated surface while carrying a load. The variability of spinal loading as a result of the number of workers during lifting tasks and the obstacles during carrying tasks might predict occasional excessive peak lumbar compression.

The aim of the present study was to quantify the spinal loading during the above mentioned lifting and carrying tasks in ironwork. Therefore, above tasks have been simulated in the laboratory and spinal loading was estimated. The weight of the handled materials was chosen based on the maximum weight that is allowed by the Dutch Labour Inspectorate to be handled: single-worker 25 kg, two-worker 50 kg, and four-worker 100 kg. All tasks were repeated 6 times to be able to quantify the variation in peak spinal loading over multiple trials. For every task, the mean, maximum and variability in peak lumber compression force was calculated.

Based on the few previous studies regarding team lifting (Dennis and Barrett, 2002; Marras et al., 1999) it is expected that team lifting will result in slightly lower mean peak compression forces. However, team lifts could also result in higher variability in peak loading over multiple repetitions, resulting in a higher maximum peak compression force. For the carrying tasks, stepping over an obstacle and up a platform is expected to result in higher mean, maximum and variability of peak compression force compared with ground level carrying. However, based on previous research (Marras et al., 1999) it is expected that carrying results in lower mean and maximal peak compression forces compared to the lifting tasks.

2. Method

2.1. Participants

Twelve ironworkers from five concrete reinforcement companies participated in this study. The companies were recruited through their employers' organisation. All participants had at least six months experience as an ironworker. All participating ironworkers were males. The mean values for age, height, weight and years of work experience were 31 (SD 8) years, 180 (SD 8) cm, 80 (SD 13) kg and 11 (SD 9) years, respectively. Before participating, all ironworkers signed an informed consent form. The experiment was approved by the local ethics committee.

2.2. Tasks

The ironworkers performed three lifting tasks and six carrying tasks that were based on a real working situation:

1) lifting a 25-kg load alone from floor level (single-worker lift; L1);
2) lifting a 50-kg load with two workers from floor level (two-worker lift; L2); and
3) lifting a 100-kg load with four workers from floor level (four-worker lift; L4).

For the carrying tasks, the ironworkers had to walk three metres for each task, including:

1) carrying a 50-kg load with two workers on level ground;
2) carrying a 100-kg load with four workers on level ground;
3) carrying a 50-kg load with two workers while stepping over a 25-cm high obstacle;
4) carrying a 100-kg load with four workers while stepping over a 25-cm high obstacle;
5) carrying a 50-kg load with two workers while stepping on a 46-cm high platform; and
6) carrying a 100-kg load with four workers while stepping on a 46-cm high platform.

Kinematics and ground reaction forces for one ironworker (the experimental ironworker) were assessed while he performed the tasks with the help of three other ironworkers (co-ironworkers). After completing the nine tasks, one of the co-ironworkers became the experimental ironworker and the measurements were repeated for the new experimental ironworker. On one measurement day, data were collected of two ironworkers of the total four ironworkers. Data collection of the other two ironworkers was performed on another measurement day. To assess the variability in peak lumbar compression forces, all of the tasks were performed six times by the experimental ironworker. The experimental ironworker performed the lifting and carrying tasks with two workers twice with each of the three co-ironworkers. During the lifting tasks with two workers, the workers were standing next to each other. The lifting and carrying tasks with four workers were performed with all three co-ironworkers in a rectangular line-up. To compensate for the differences in height between the co-ironworkers while these tasks were being performed, the co-ironworkers rotated positions such that each co-ironworker lifted and carried the 100-kg load twice from the corner diagonally across from the experimental ironworker.

2.3. Load type

In accordance with what was observed in practice (Visser et al., 2014), the single-worker lifts were performed with a 6.35-m (ø 0.25 m) iron bar weighing 25 kg (Fig. 1a), and the lifting and carrying tasks with two workers were performed with two 6.35-m (ø 0.25 m) iron bars each weighing 25 kg (Fig. 1b). A 5.95 × 2.30-m (ø 0.10 m) iron lattice weighing 100 kg was used for the lifting and carrying tasks with four workers (Fig. 1c).

2.4. Procedure

During the lifting tasks, the experimental ironworker stood beside a force plate. The researcher counted down to start the measurement, and the experimental ironworker stepped onto the force plate and lifted the load from floor level to knuckle height. The load was held at knuckle height for a few seconds, and lowered to floor height. For the team lifts, the co-workers had to lift the load from the floor to knuckle height, but the coordination between the experimental- and co-ironworkers was self-paced. During the carrying tasks, the load was already lifted 1 m in front of the force plate. After the countdown to start the measurement, the ironworkers had to walk 3 m with the load while the experimental ironworker walked on the force plate (Fig. 2a). For the obstacle tasks, a rope was stretched across the centre of the force plate at a height of 25 cm (Fig. 2b). The experimental ironworkers at the rear end of the load (and the co-ironworker at the rear end of the load during the four-worker carrying tasks with 100 kg) were asked to place one foot on the force plate in front of the rope, step over the rope and place the other foot on the force plate behind the rope; the total distance covered (3 m) was the same as the distance in other carrying tasks. The platform tasks were performed in the same

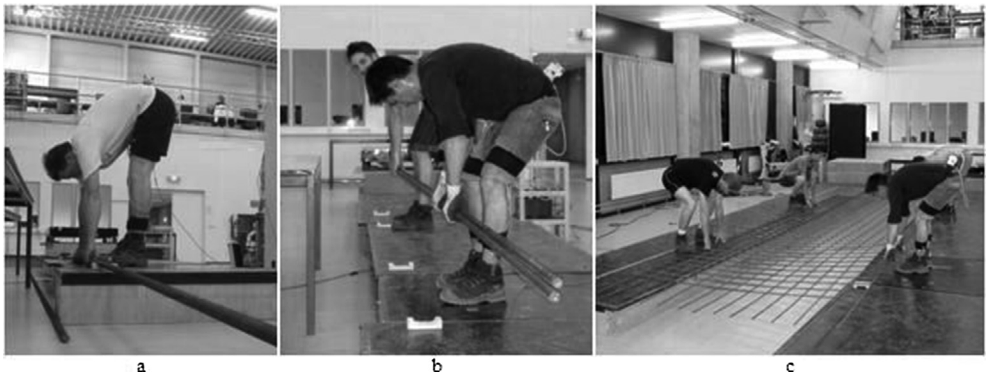

Fig. 1. Pictures of the 25-kg single-worker lifting task (a), the 50-kg two-worker lifting task (b) and the 100-kg four-worker lifting task (c).

manner as the carrying tasks. A second force plate was placed at a height of 46 cm above the first force plate, and the experimental ironworkers at the front of the load (and the co-ironworker at the front of the load during the four-worker carrying tasks with 100 kg) were asked to step onto the second force plate (Fig. 2c). The ironworkers were encouraged to lift and carry the load in the same manner as they normally would at a work site.

2.5. Biomechanical analysis

The body kinematics of the feet, lower legs, upper legs and pelvis of the experimental ironworker were measured using an Optotrak system (Northern Digital, Waterloo ON, Canada) with a sample rate of 50 samples/sec. Ground reaction forces were measured with two custom-made 1 m × 1 m force plates (sample rate 100 samples/s). Anthropometric data for the lower extremities and pelvis of the experimental ironworkers were obtained (Faber et al., 2011). The lower-body kinematics, ground reaction forces and anthropometrics were entered into a 3D bottom-up inverse dynamics model (Kingma et al., 1996) to calculate lumbar (L5S1) moments. Subsequently, based on these lumbar moments, lumbar compression forces for each task were calculated using the regression equations of van Dieën and Kingma (2005), with the adjustments of Faber et al. (2009a).

For the compression force time-series of each of the nine experimental tasks (three lifting and six carrying tasks), the peak lumbar compression forces of each of the six repetitions was defined as the highest lumbar compression force during a trial. Subsequently, for each set of six lumbar compression peaks, the mean, the maximum and the variability (defined as the standard deviation of the six repetitions for each task per experimental ironworker) were determined. In addition, the contribution of the ironworkers, trials and tasks to the variance in peak lumbar compression forces was estimated.

2.6. Statistics

To examine the differences in mean, maximum and variability of peak lumbar compression forces of a single-worker lift, a two-worker lift and a four-worker lift, three one-way (one, two or four workers) ANOVAs for repeated measures were used. To test the effect of stepping over an obstacle and up a platform during carrying tasks compared with carrying on level ground on mean, maximum and variability of peak lumbar compression forces, three one-way (level ground, obstacles or platform carrying) ANOVAs for repeated measures were used for both a 50-kg load and a 100-kg load. In addition, to test whether the mean, maximum and variability of peak lumbar compression forces were different between the lifting tasks and the carrying tasks, three one-way ANOVAs for repeated measures were used for both a 50-kg load and a 100-kg load.

When the ANOVA revealed significant differences, post hoc analyses were conducted using Bonferroni adjustments. Sphericity was tested using Mauchly's Test of Sphericity and the number of degrees of freedom was adjusted using the Greenhouse-Geisser adjustment if necessary. A Variance Components Analysis was performed to assess the contribution of workers, trials and tasks to the variance in peak lumbar compression forces during the three lifting tasks, and both carrying tasks (carrying a 50-kg load and carrying a 100-kg load). The tests were carried out using SPSS 19.0 (SPSS, Inc., Chicago, IL, USA). A significant difference was defined as $p < 0.05$.

3. Results

3.1. Lifting tasks

Table 1 shows an overview of the mean, maximum and variability of the peak lumbar compression forces during the single-

Fig. 2. Carrying on level ground with a 50-kg iron bar or a 100-kg iron lattice (a), stepping over an obstacle while carrying a 50-kg iron bar or a 100-kg iron lattice (b) and stepping up a platform while carrying a 50-kg iron bar or a 100-kg iron lattice (c).

Table 1
Overview of the mean (SD) mean, maximum and variability of the peak lumbar compression forces during the lifting tasks of ironworkers ($n = 12$).

	L1		L2		L4	
	Mean	SD	Mean	SD	Mean	SD
Mean	5139	635	5307	806	4770	807
Maximum	5524	717	5742	1033	5156	823
Variability	243	173	296	207	316	156

L1: 25-kg single-worker lifts; L2: 50-kg two-worker lifts; L4: 100-kg four-worker lifts.

worker, two-worker and four-worker lifts. Statistically significant higher mean and maximum peak lumbar compression forces were found for the 50-kg two-worker lifts compared to the 100-kg four-worker lifts (Table 2). Compared to the 25-kg single-worker lifts, the mean peak lumbar compression forces of the 100-kg four-worker lifts were significantly lower. No statistically significant differences were found for the variability of the peak lumbar compression forces. Due to a measurement error during one trial, resulting in an abnormally low peak compression force (2266 N), the mean peak lumbar compression force of one ironworker was calculated over five trials instead of six. The Variance Components Analysis showed that 64% of the variance was contributed to the between-worker variance, 1% to the between-trial variance (=within-worker variance), and 10% to the between-tasks variance. The remaining 25% was attributed to an error component.

3.2. Carrying tasks

The results of the platform trials of two ironworkers were unusable because data from the lowest force plate during these trials were missing. Therefore, the mean, maximum and variability of peak lumbar compression forces were calculated from the remaining ten experimental ironworkers. Table 3 shows an overview of the mean, maximum and variability of the peak lumbar compression forces for the 50-kg two-worker carrying tasks and the 100-kg four-worker carrying tasks. For carrying a 50-kg load with two workers and a 100-kg load with four workers, the carrying on level ground tasks showed significantly lower mean and maximum peak compression forces. Higher values were found for stepping up a platform while carrying. The variability of the peak lumbar compression force while stepping over an obstacle was significantly higher compared to carrying on level ground for both loads. For both carrying tasks, the between-tasks variance was the largest component of the Variance Component Analysis, 90% and 92% respectively for the 50-kg two-worker- and 100-kg four-worker carrying tasks. The between-worker variance contributed for 5% and 3% respectively, and for both carrying tasks the component of the between-trial variance was 0%. The other 5% in both carrying tasks was attributed to an error component.

3.3. Lifting vs. carrying

The mean and maximum peak compression forces of the 50-kg two-worker lifting task were significantly lower compared to the carrying while stepping up a platform task, but significantly higher compared to carrying on level ground and carrying a load of 50 kg over an obstacle. The mean and maximum peak compression forces of the 100-kg four-worker lifting task did not significantly differ from the carrying over an obstacle task, but was significantly higher compared with carrying on level ground and significantly lower compared with the carrying while stepping up a platform. The variability of the peak compression forces were higher while carrying over an obstacle or while stepping up a platform compared to the variability of lifting a 100-kg load with four workers.

4. Discussion

This study examined the lumbar compression forces of handling loads, which occurs daily at construction sites. It was found that a 50-kg two-worker lift resulted in higher mean and maximum peak lumbar compression forces compared with a 100-kg four-worker lift. No differences were found for the variability of the peak lumbar compression forces during the lifting tasks. Carrying a load while stepping over an obstacle resulted in higher mean and maximum peak lumbar compression forces compared with carrying on level ground for carrying 50-kg with two workers and

Table 2
Repeated-measures ANOVAs results and p-values for the mean, maximum and variability of the peak lumbar compression forces during the lifting and carrying tasks.

	Mean	Post hoc	Maximum	Post hoc	Variability	Post hoc
ANOVAs for the effect of the number of workers on the lifting tasks						
Lifting	$F(2,22) = 11.198$ $\mathbf{p < 0.001}$	L1 > L4; $\mathbf{p = 0.020}$ L1 = L2; $p = 0.633$ L2 > L4; $\mathbf{p = 0.001}$	$F(2,22) = 6.061$ $\mathbf{p = 0.008}$	L1 = L4; $p = 0.095$ L1 = L2; $p = 0.523$ L2 > L4; $\mathbf{p = 0.047}$	$F(1.211,13.322) = 0.806$[a] $p = 0.409$	
ANOVAs for the effect of the carrying tasks						
Carrying 50 kg	$F(2,18) = 204.238$ $\mathbf{p < 0.001}$	Cl < Co; $\mathbf{p = 0.006}$ Cl < Cp; $\mathbf{p < 0.001}$ Co < Cp; $\mathbf{p < 0.001}$	$F(2,18) = 149.042$ $\mathbf{p < 0.001}$	Cl < Co; $\mathbf{p = 0.011}$ Cl < Cp; $\mathbf{p < 0.001}$ Co < Cp; $\mathbf{p < 0.001}$	$F(2,18) = 5.012$ $\mathbf{p = 0.019}$	Cl < Co; $\mathbf{p = 0.049}$ Cl = Cp; $p = 0.113$ Co = Cp; $p = 1.000$
Carrying 100 kg	$F(2,18) = 266.371$ $\mathbf{p < 0.001}$	Cl < Co; $\mathbf{p < 0.001}$ Cl < Cp; $\mathbf{p < 0.001}$ Co < Cp; $\mathbf{p < 0.001}$	$F(2,18) = 182.983$ $\mathbf{p < 0.001}$	Cl < Co; $\mathbf{p < 0.001}$ Cl < Cp; $\mathbf{p < 0.001}$ Co < Cp; $\mathbf{p < 0.001}$	$F(2,18) = 10.828$ $\mathbf{p = 0.001}$	Cl < Co; $\mathbf{p = 0.012}$ Cl = Cp; $p = 0.099$ Co = Cp; $p = 0.063$
ANOVAs for the comparison of the lifting tasks with the carrying tasks						
50-kg two-worker tasks	$F(3,27) = 166.103$ $\mathbf{p < 0.001}$	L2 > Cl $\mathbf{p < 0.001}$ L2 > Co; $\mathbf{p < 0.001}$ L2 < Cp; $\mathbf{p < 0.001}$	$F(3,27) = 99.605$ $\mathbf{p < 0.001}$	L2 Cl; $\mathbf{p < 0.001}$ L2 > Co; $\mathbf{p = 0.003}$ L2 < Cp; $\mathbf{p < 0.001}$	$F(3,27) = 4.317$ $\mathbf{p = 0.013}$	L2 = Cl; $p = 1.000$ L2 = Co; $p = 0.309$ L2 = Cp; $p = 0.199$
100-kg four-worker tasks	$F(3,27) = 185.235$ $\mathbf{p < 0.001}$	L4 > Cl; $\mathbf{p < 0.001}$ L4 = Co; $p = 0.081$ L4 < Cp; $\mathbf{p < 0.001}$	$F(1.559,14.031) = 136.688$[a] $\mathbf{p < 0.001}$	L4 > Cl; $\mathbf{p < 0.001}$ L4 = Co; $p = 1.000$ L4 < Cp; $\mathbf{p = 0.001}$	$F(3,27) = 13.004$ $\mathbf{p < 0.001}$	L4 = Cl; $p = 1.000$ L4 < Co; $p = 0.004$ L4 < Cp; $p = 0.048$

L1 = 25-kg single-worker lifts; L2 = 50-kg two-worker lifts; L4 = 100-kg four-worker lifts; Cl = Carrying on level ground tasks; Co = Carrying a load over an obstacle; Cp = Carrying a load onto a platform.
Significant effects ($p < 0.05$) are indicated in bold type.
[a] Greenhouse-Geisser adjustment.

Table 3
Overview of the mean (SD) mean, maximum and variability of the peak lumbar compression forces during the 50-kg two-worker carrying tasks and the 100-kg four-worker carrying tasks of ironworkers ($n = 10$).

	50-kg two-worker						100-kg four-worker					
	Cl		Co		Cp		Cl		Co		Cp	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mean	2162	385	3187	961	7483	1009	2966	404	3894	606	7823	847
Maximum	2645	517	3898	1105	8162	1129	3427	672	4777	542	8435	949
Variability	287	136	527	230	477	134	307	137	608	190	447	145

Cl = Carrying on level; Co = Carrying a load over an obstacle; Cp = Carrying a load onto a platform.

carrying 100-kg with four workers, although these were lower or equal to lifting a 50-kg or an 100-kg load. The variability of the peak lumbar compression forces during the carrying tasks was higher while stepping over an obstacle compared to carrying on level ground for carrying 50-kg and 100-kg loads. Compared to lifting, carrying a 100-kg load while stepping over an obstacle or up a platform led to a higher variability.

4.1. Team lifting

The mean peak lumber compression forces for single-worker lifts found in this study were in line with peak lumbar compression forces (range 4834–5744 N) of masonry workers while lifting blocks of 6–16 kg (Faber et al., 2009b) and maximum peak lumbar compression forces with Dennis and Barrett (2002) (5659 N). In contrast to Marras et al. (1999) and Dennis and Barrett (2002), this study showed no difference in the mean and maximum peak lumbar compression forces when 50-kg two-worker lifts were compared with a 25-kg single-worker lift. However, a reduction in the mean and maximum peak lumbar compression forces was found for 100-kg four-worker lifts.

These findings can be explained by the positions of the team members with respect to each other. During the 50-kg two-worker lift, the team members were standing next to each other, whereas the team members were facing each other during the 100-kg four-worker lifts in the rectangular line-up. Considering the positions of the team members, the findings of the present study were aligned with the findings by Marras et al. (1999) and Dennis and Barrett (2002). In these studies, single-worker- and two-worker lifts were compared where workers were facing each other during the two-worker lifts. According to Dennis and Barrett (2002), facing each other during team lifts is beneficial because the worker is able to exert a larger horizontal hand force (i.e. a pulling force). When the hands are below the spine, the moment created by this horizontal hand force at the lower back is the reverse of the moment created by the vertical hand force acting on the lifter, resulting in a smaller net lumbar moment, and therefore a smaller peak lumbar compression force. Despite the favourable facing-each-other position of the workers during 100-kg four-worker lifts, the mean and maximum peak lumbar compression forces were still high. Because the loads were lifted from floor level, a large component of the lumbar compression forces is explained by trunk flexion of the workers, as shown by the constant values of regression analyses of individual lifts (Faber et al., 2009b; Hoozemans et al., 2008), 3494 N and 3817 N, respectively. The effect of increasing lifting height on the compression force during team lifts needs to be the subject of further studies. The assumption that increasing the number of workers lifting a load led to an inadequate coordination between the workers and, therefore, higher spinal loads due to an unequal mass distribution was not observed in the variability of the peak lumbar compression forces. Additionally, the Variance of Components Analysis revealed that the between worker component contributed to the largest amount of the variance, more than 60%. Although the coordination between the ironworkers was self-paced, the experience of ironworkers in practice may have caused the loads to be lifted simultaneously. In addition, the timing differences may not have an effect on the peak lumber compression forces but may have caused a prolonged duration of lifting a load. When looking at the time differences, future studies should also take the duration of a lift into account.

4.2. Effect of obstacles and elevated surfaces

During carrying tasks, stepping over obstacles and up platforms caused higher mean and maximum peak lumbar compression forces compared with carrying on level ground tasks, with the absolute highest mean and maximum peak lumbar compression forces when the workers had to step up a platform. It was found by Rohlmann et al. (2014) that ascending stairs resulted in higher resultant forces on vertebral body replacements when compared with level walking. As an explanation, Rohlmann et al. (2014) stated that the subjects in their study bent their upper body while ascending stairs. The forward bend resulted in a change in centre of mass of the upper body with respect to the L5S1 position changes. Due to the forward movement during the carrying tasks, and a vertical distance of 46 cm between the platform and the floor in our study, ironworkers may have an increased inclination of the trunk to avoid a disturbance in their balance while carrying. Besides the change in centre of mass of the upper body, an extra component as a result of an acceleration of the trunk and the load in a vertical direction might also explain the high mean and maximum peak lumbar compression forces while stepping on a platform. Carrying over obstacles and platforms increased the variability of the peak lumbar compression forces, which may indicate an increased risk of occasional excessive loading. Thus, walking routes on construction sites should be free of obstacles and platforms while objects are being carried to avoid high and variable peak lumbar compression forces.

4.3. Strengths and weaknesses

This study was performed to compare lumbar compression forces of handling tasks which occur in practice. For this comparison, loads and handling methods of a typical workday at a construction site were used to compare the peak lumbar compression forces during the lifting and carrying tasks. This implied that the lumbar compression forces of the carrying 50 kg tasks and the 100 kg tasks could not be compared with each other. The different carrying methods of the objects might result in differences in the lumbar compression forces that could not be ascribed to the number of workers carrying a load. To compare the different carrying tasks for different masses of loads, experimental laboratory studies with the same kind of load should be conducted. Additionally, future studies should also compare the compression forces over time while team lifting and team carrying practice based fixed loads to see whether only differences in peak compression forces occur or if the compression forces are higher over time while lifting and carrying over an obstacle and on a platform.

The results of this study are applicable for ironworkers, but cannot be generalised to team lifting or carrying in general with loads of 50 or 100 kg. Whether team lifting in itself is not beneficial for reducing spinal loads, but only when workers are facing each other, must be proven by more fundamental research in which objects and masses are standardised.

4.4. Conclusion and implications

Mean and maximum peak lumbar compression forces significantly increased by 537 N and 587 N for the 50-kg two-worker lifts relative to the 100-kg four-worker lifts. No significant differences were found in the variability of the peak lumbar compression forces in lifting as a result of the number of workers varying between one, two and four.

The lowest mean and peak lumber compression forces were found during carrying on level ground tasks for carrying both 50-kg loads and 100-kg loads. This is in line with the general assumption that carrying is less demanding for the back. However, this study showed that stepping up a platform while carrying a load resulted in the highest compression forces, even compared with the lifting tasks. Moreover, carrying the 100-kg load over an obstacle resulted in no statistically different mean or maximum peak compression forces compared to lifting 100 kg. Mean and maximum peak lumbar compression forces while carrying and stepping over an obstacle and up a platform were higher than recommended threshold limits for lumbar compression forces: 3.4 kN (Waters et al., 1993) and 5.7 kN (Jäger and Luttmann, 1991). Therefore, additional studies should also take carrying tasks into account when assessing spinal loading during manual handling tasks.

To reduce peak lumbar compression forces, lifting a fixed load mass with additional workers is advised. However, it was found that the benefits of additional workers are task-dependent (e.g., carrying vs. lifting) (Kim et al., 2012). Additionally, the question remains whether the use of an additional worker is feasible in practice, because it was observed in practice that a load mass of more than 50 kg was frequently lifted manually, with the lifts being done with less than the appropriate number of workers (Visser et al., 2014). The main explanation of the ironworkers for lifting a load with a maximum of two workers was that it required a less space and less coordination between ironworker to lift and carry the load compared to three or four workers.

Two overall recommendations can be made: firstly, efforts should be made to prevent manual lifting and carrying of objects in ironwork to reduce exposure of high compression forces during lifting and carrying; secondly, when mechanical transportation is not possible and loads are handled manually, carrying routes should be free of any obstacles to be overcome.

References

Buchholz, B., Paquet, V., Wellman, H., Forde, M., 2003. Quantification of ergonomic hazards for ironworkers performing concrete reinforcement tasks during heavy highway construction. AIHA J. 64 (2), 243–250.

da Costa, B.R., Vieira, E.R., 2010. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am. J. Indust. Med. 53 (3), 285–323.

Dennis, G.J., Barrett, R.S., 2002. Spinal loads during individual and team lifting. Ergonomics 45 (10), 671–681.

Dennis, G.J., Barrett, R.S., 2003a. Spinal loads during two-person team lifting: effect of matched versus unmatched standing height. Int. J. Indust. Ergon. 32 (1), 25–38.

Dennis, G.J., Barrett, R.S., 2003b. Spinal loads during two-person team lifting: effect of load mass distribution. Int. J. Indust. Ergon. 32 (5), 349–358.

van Dieën, J.H., Kingma, I., 2005. Effects of antagonistic co-contraction on differences between electromyography based and optimization based estimates of spinal forces. Ergonomics. 48 (4), 411–426.

Dutch Labour Inspectorate, 2012. Fysieke belasting in de bouw – veilig en gezond werken (Physical Work Demands in the Construction Industry). Inspectie Sociale Zaken en Werkgelegenheid, Utrecht (in Dutch).

Faber, G.S., Kingma, I., Bakker, A.J.M., van Dieën, J.H., 2009a. Low-back loading in lifting tow loads beside the body compared to lifting one load in front of the body. J. Biomech. 42, 35–41.

Faber, G.S., Kingma, I., Kuijer, P.P.F.M., van der Molen, H.F., Hoozemans, M.J.M., Frings- Dresen, M.H.W., van Dieën, J.H., 2009b. Working height, block mass and one- vs. two-handed block handling: the contribution to low back and shoulder loading during masonry work. Ergonomics. 52 (9), 1104–1118.

Faber, G.S., Kingma, I., van Dieën, J.H., 2011. Effect of initial horizontal object position on peak L5/S1 moments in manual lifting is dependent on task type and familiarity with alternative lifting strategies. Ergonomics 54 (1), 72–81.

Griffith, L.E., Shannon, H.S., Wells, R.P., Walter, S.D., Cole, D.C., Côté, P., Frank, J., Hogg- Johnson, S., Langlois, L.E., 2012. Individual participant data meta-analysis of mechanical workplace risk factors and low back pain. Am. J. Public Health 102 (2), 309–318.

Hartmann, B., Fleischer, A.G., 2005. Physical load exposure at construction sites. Scand. J. Work Environ. Health. 31 (Suppl. 2), 88–95.

Haslam, R.A., Hide, S.A., Gibb, A.G.F., Gyi, D.E., Pavitt, T., Atkinson, S., Duff, A.R., 2005. Contributing factors in construction accidents. Appl. Ergon. 36 (4), 401–415.

Health Council of the Netherlands, 2012. Manual Lifting at Work. Health Council of the Netherlands, The Hague. http://www.gr.nl/sites/default/files/201236Tillentijdenswerk.pdf. Publication no. 2012/36. Tillen tijdens werk (in Dutch).

Hoogendoorn, W.E., van Poppel, M.N.M., Bongers, P.M., Koes, B.W., Bouter, L.M., 1999. Physical load during work and leisure time as risk factors for back pain. Scand. J. Work Environ. Health 25 (5), 387–403.

Hoozemans, M.J.M., Kingma, I., de Vires, W.H.K., van Dieën, J.H., 2008. Effect of lifting height and load mass on low back loading. Ergonomics 51 (7), 1053–1063.

Jäger, M., Luttmann, A., 1991. Compressive strength of lumbar spine elements related to age, gender, and other influencing factors. In: Anderson, P.A., Hobart, D.J., Danoff, J.V. (Eds.), Electromyographical Kinesiology. Elsevier Science, Amsterdam, pp. 291–294.

Kim, S., Nussbaum, M.A., Jia, B., 2012. The benefits of an additional worker are task-dependent: assessing low-back injury risks during prefabricated (panelized) wall construction. Appl. Ergon. 43, 843–849.

Kingma, I., de Looze, M.P., Toussaint, H.M., Klijnsma, H.G., Bruijnen, T.B.M., 1996. Validation of a full body 3-D dynamic linked segment model. Hum. Mov. Sci. 15 (6), 833–860.

Koningsveld, E.A.P., van der Grinten, M., van der Molen, H.F., Krause, F., 2005. A system to test the ground surface conditions of construction sites – for sage and efficient work without physical strain. Appl. Ergon. 36 (4), 441–448.

Kuiper, J.I., Burdorf, A., Frings-Dresen, M.H.W., Kuijer, P.P.F.M., Spreeuwers, D., Lötters, F.J., Miedema, H.S., 2005. Assessing the work-relatedness of nonspecific low-back pain. Scand. J. Work Environ. Health 31 (3), 237–243.

Lee, T.H., 2004. Maximum isometric lifting strengths of men in teamwork. Hum. Factors 46 (4), 686–696.

Lee, K.S., Lee, J.H., 2001. A study of effiency of two-man lifting work. Int. J. Ind. Ergon. 28 (3–4), 197–202.

Lötters, F., Burdorf, A., Kuiper, J., Miedema, H., 2003. Model for the work-relatedness of low-back pain. Scand. J. Work Environ. Health 29 (6), 431–440.

Marras, W.S., Davis, K.G., Kirking, B.C., Granata, K.P., 1999. Spine loading and trunk kinematics during team lifting. Ergonomics 42 (10), 1258–1273.

Mital, A., Motorwala, A., 1995. An ergonomic evaluation of steel and composite access covers. Int. J. Indust. Ergon. 15 (4), 285–296.

Paquet, V., Punnett, L., Woskie, S., Buchholz, B., 2005. Reliable exposure assessment strategies for physical ergonomics stressors in construction and other non-routinized work. Ergonomics 48 (9), 1200–1219.

Rohlmann, A., Dreischarf, M., Zander, T., Graichen, F., Bergmann, G., 2014. Loads on a vertebral body replacement during locomotion measured in vivo. Gait Posture 39, 750–755.

Sharp, M.A., Rice, V.J., Nindl, B.C., Williamson, T.L., 1997. Effects of team size on the maximum weight bar lifting strength of military personnel. Hum. Factors 39 (3), 481–488.

Visser, S., van der Molen, H.F., Kuijer, P.P.F.M., Hoozemans, M.J.M., Frings-Dresen, M.W.H., 2014. Evaluation of team lifting on work demands, workload and workers' evaluation: an observational field study. Appl. Ergon. 45 (6), 1597–1602.

Waters, T.R., Putz-Anderson, V., Grag, A., Fine, L.J., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36 (7), 749–776.